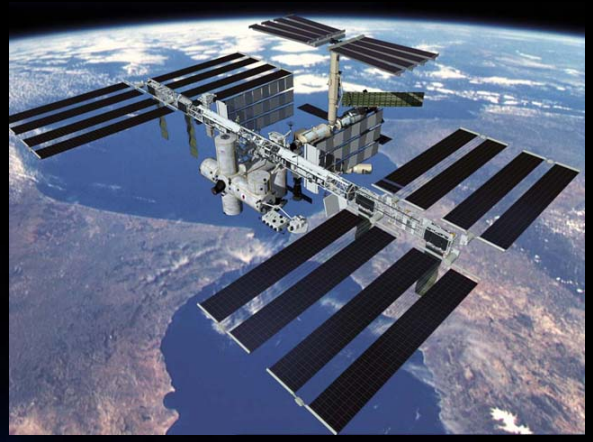
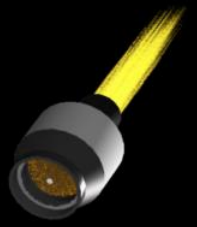
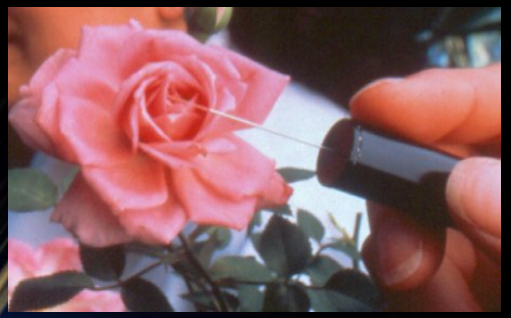
May 2014



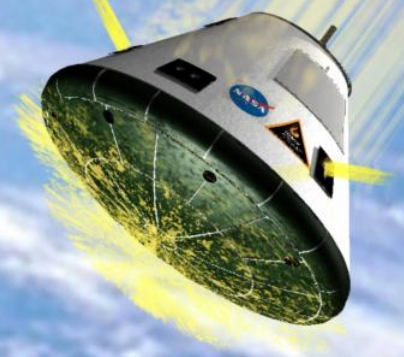




Microgravity-Based Commercialization Opportunities

for Material Sciences and Life Sciences:

A Silicon Valley Perspective



Space Portal
Level 2 Emerging Space Office
NASA Ames Research Center
Ioana Cozmuta, Ph.D., Science and Technology Corporation
Daniel Rasky, Ph.D. NASA ARC
Lynn Harper, NASA ARC
Robert Pittman, Lockheed-Martin

Objective

Assess the potential of microgravity for public benefits and economic growth over the next decade.

1. Potential	What are the benefits of microgravity for material and life sciences? How deep is the understanding of the microgravity phenomenon? How can microgravity products or insights affect the state-of-the-art on Earth? What is their value/relevance in the current landscape of applications?
2. Credibility	How credible are the microgravity based results? What is the current appreciation and value of the microgravity based applications that have previously returned value to the tax payers? Are there revenue generating companies from a microgravity based product?
3. Accessibility & Awareness	Who is aware of microgravity and to what extent? How structured/accessible is the scientific and commercial value of microgravity? When challenged by a technical problem caused by gravity, do scientists in either the academic or the private sectors think of using microgravity to solve it?
4. Interest	To what extent is there interest in pursuing microgravity based investigations for new knowledge and product innovation? What are the target areas that would benefit most from R&D in microgravity? What is the industry specific infusion point for microgravity driven discoveries?

Strategy

Commercial Microgravity Products	• Online research reviewing the entire ISS database (including the one behind the firewall), selected scientific literature, and spinoff databases to identify microgravity products for specific application areas. • One-on-one interviews with PI's of microgravity investigations • Discussions with industry scientists, chief technology and executive officers and venture capitalists from the private sector (mostly Silicon Valley) • Summarized scientific publications, patents and spinoffs per application
Potential Microgravity Benefits and Solutions	• Microgravity seminars at major universities across the US • One-on-one discussions with faculty and students of various disciplines relevant to microgravity R&D. • In-depth examination of promising topic areas, especially **comparison and validation against current SOA on ground** • Technical exchanges among experts in microgravity research, PIs, microgravity commercial service providers, recognized scientists at the cutting edge of terrestrial SOA and potential commercial users of microgravity R&D .

Approach

1. **Identify products originating from microgravity research,** describe their known technological advantages over Earth-manufactured counterparts, and provide clear traceability from microgravity R&D through product development.

2. **Organize results with relevance to a specific application (across disciplines)**; results from most microgravity investigations branch out in a wide (sometimes unexpected) variety of areas

3. **Identify potential microgravity-based technical solutions for commercial applications** and their possible infusion points into the product development cycle, using results from step (1) and survey of existing market values to provide realism.

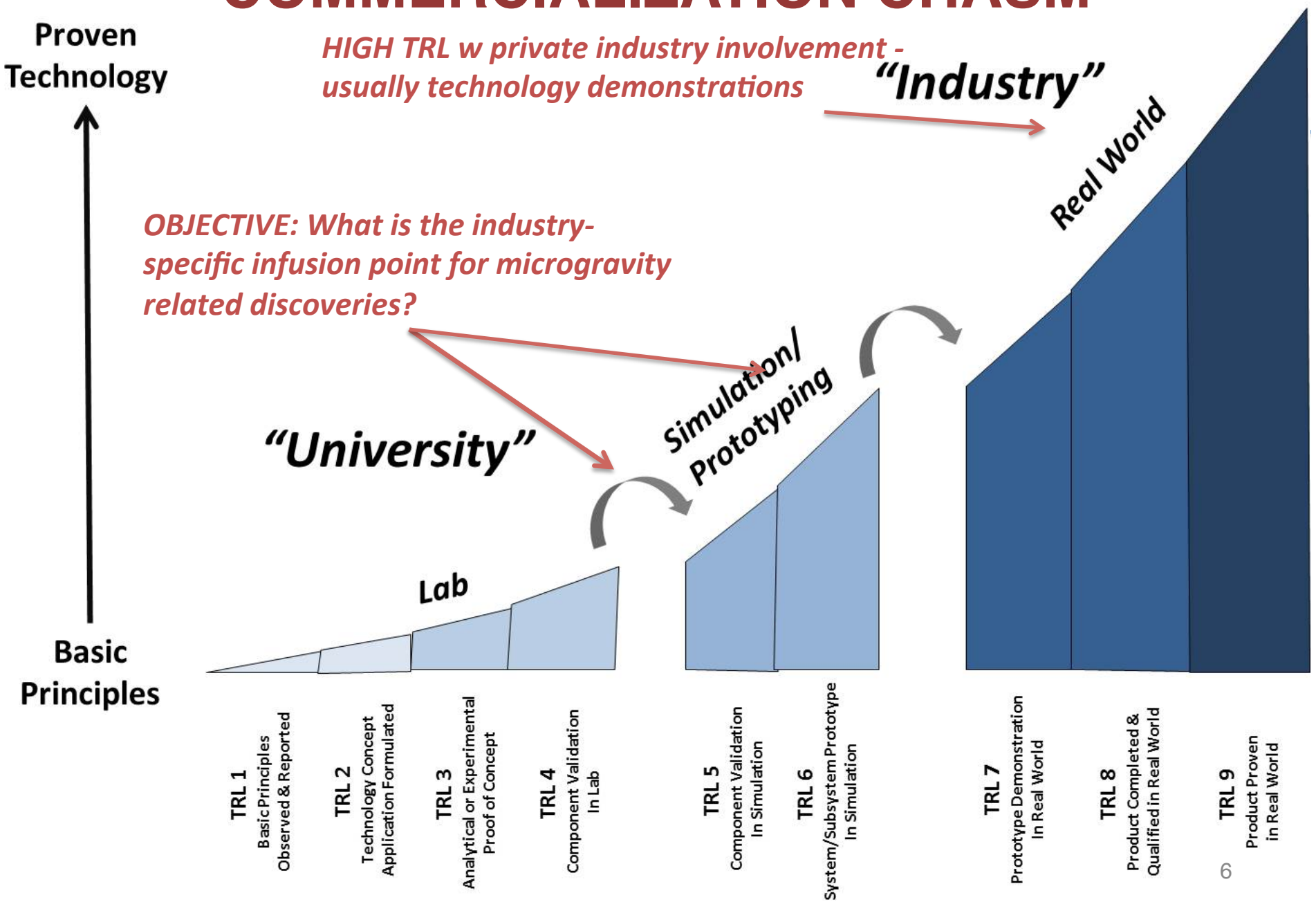
4. **Evaluate potential commercial benefits from microgravity R&D** over the next decade through the lens of the current state-of-the-art of analogous processes on the ground and anticipated industrial high-tech trends.

5. **Select topics for in-depth case studies and obtain independent review and validation of findings** by both technical and business experts for selected case studies and selected potential products.

Findings

1. Potential	**The story is better than most think.** The fundamental benefits of microgravity are significant. The fundamental hypotheses are sound. Products from space have evident superior technical performance.
2. Credibility	**Skepticism exists but can be addressed.** Credibility varies. The successes emerged from the previous NASA investments in microgravity commercialization (spinoffs with ROI) are essential to attract commercial interest. More contemporary examples are needed since the value of the past successes is depreciating in some cases.
3. Accessibility & Awareness-	**Awareness is very low.** Unless previously involved with spaceflight, the number of commercial and even academic researchers seeking technical solutions in microgravity is very low. Space is perceived as too high risk for private investors. **Accessible information is very low.** A public, searchable, dynamically updated, commercial microgravity database is needed for easy access of information and to allow companies to do their own due diligence.
4. Interest	**The interest is considerable** especially when the correct message is sent out. There are very promising areas struggling for funding. There are unexplored areas with great future potential. Providing unrestricted application-relevant (rather than discipline) information is critical for attracting high-tech industry. Identifying industry specific infusion points for microgravity driven discoveries is key.

COMMERCIALIZATION CHASM



Potential and credibility

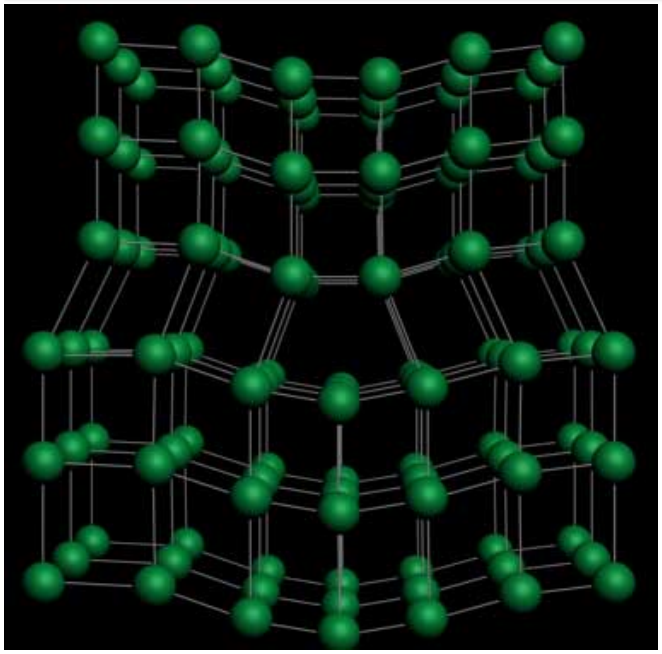
The story is better than most think…

- When the force of gravity is removed other forces (surface tension, capillary forces) become predominant and drive a different system dynamics

- Gravity is a physical parameter that together with pressure and temperature define the state of a system.

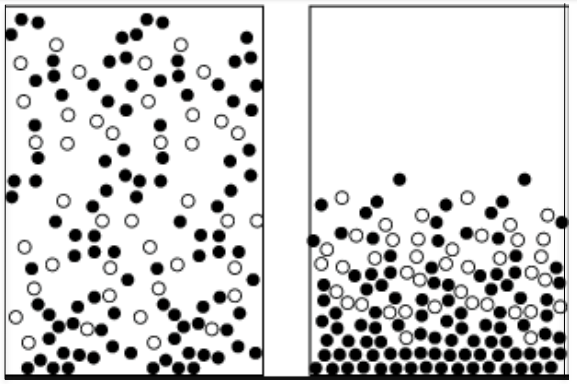
- Historically, major breakthrough and innovations were achieved when systems were studied, for example, at low temperatures.

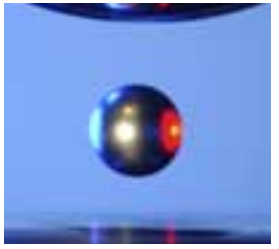
MICROGRAVITY BENEFITS FOR MATERIAL SYSTEMS



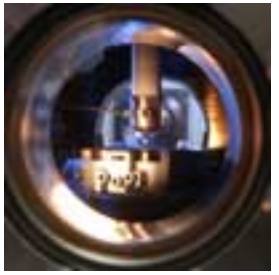
- Defect free
- Homogeneous
- Controlled, symmetric growth
- Avoidance of nucleation or single nucleation
- Higher resolution

- No solute buildup
- No sedimentation
- No convection

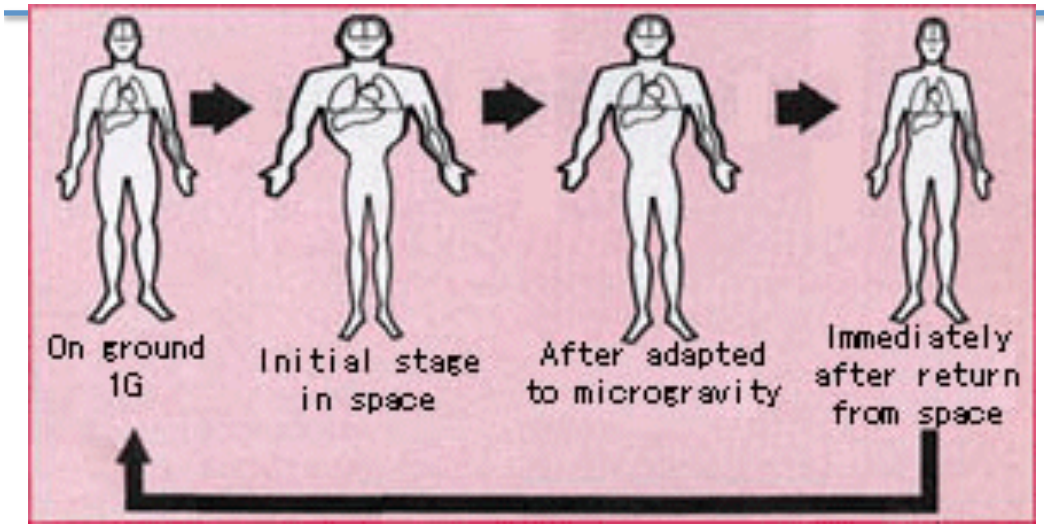




- Containerless processing
- Free suspensions
- Perfect spherical shape
- No wetting

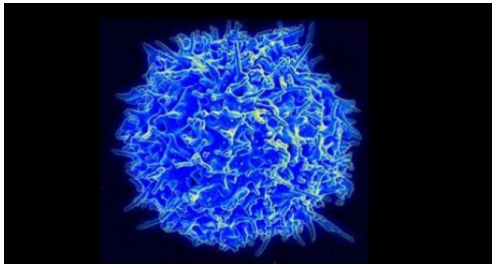


MICROGRAVITY BENEFITS FOR LIFE SCIENCES



Microgravity is evolutionarily novel and enables new understanding of living systems that can be used for medicine and biotech.

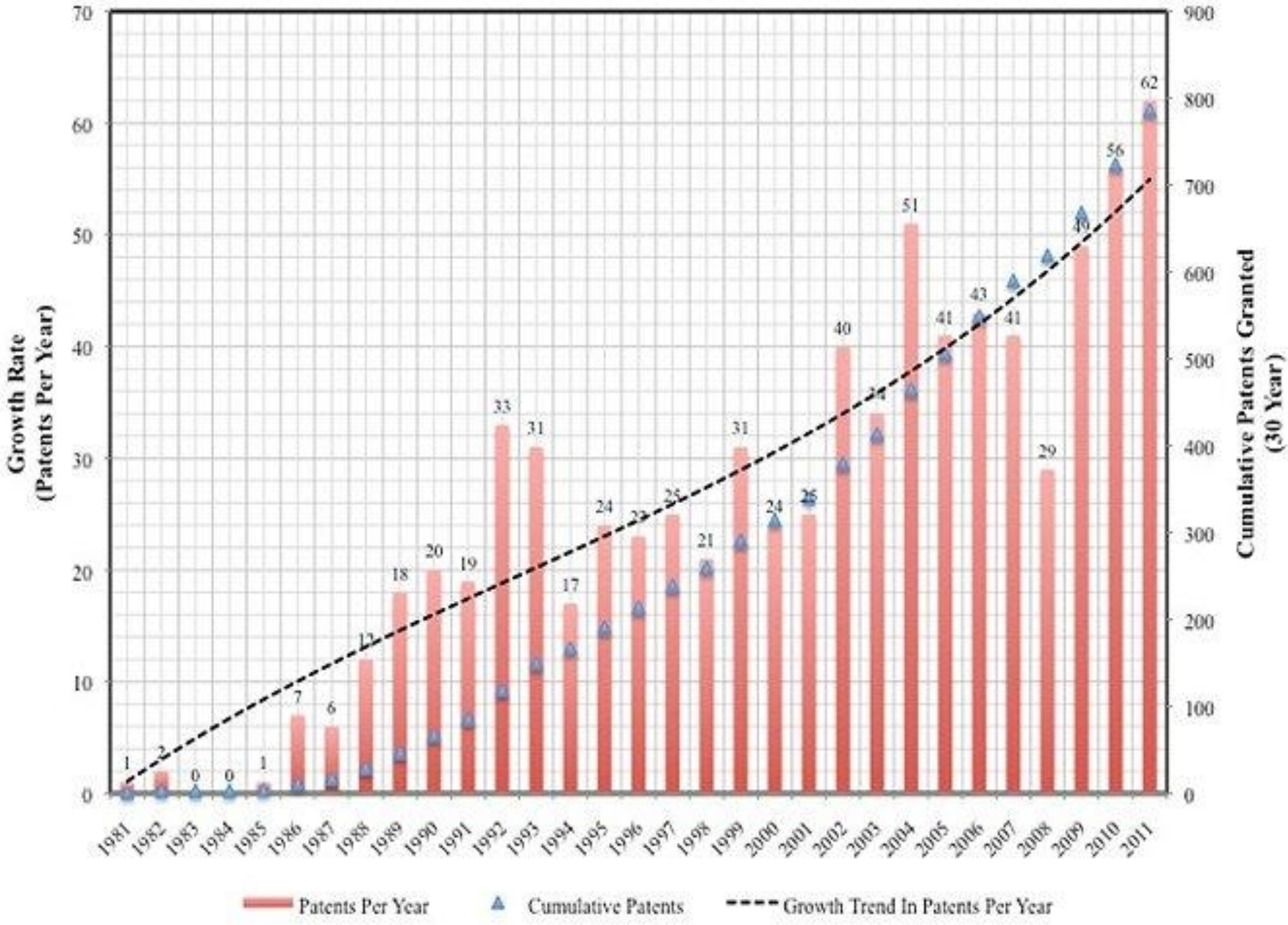
Commercial biosciences and pharmaceutical companies have flown experiments in space since the 1980s.



Response to gravity is complex.

All levels of biological organization, cells, tissues, organs, organisms, are affected by gravity/microgravity, often in novel and useful ways, sometimes in ways that allow medical problems on Earth to be better studied.

As biotech companies have found, novel environments offer novel biological responses useful for industry, medicine, and agriculture.


Microgravity-Related Patents: 30 Year Growth Trend
Growth Rate (Patents Per Year)
Cumulative Patents Granted (30 Year)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
900
1 2 0 0 1 7 6 12 18 20 19 33 31 17 24 23 25 21 31 24 26 40 34 51 41 43 41 29 49 56 62
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Patents Per Year
Cumulative Patents
Growth Trend In Patents Per Year

Findings: Quantity of ISS R&D for commercial terrestrial applications is not high enough to develop the potential microgravity offers for economic growth

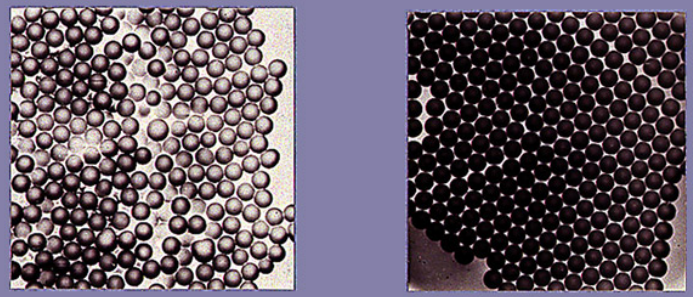
Expedition	31-32 May-July 2012	33-34 Oct-Dec, 2012	35-36 Mar-May 2013*	37-38 Sep-Nov 2013*	39-40 Mar-May 2014	40-41 Mar-May 2014	41-42 Mar-May 2014
Total Investigations – including international	150	145	138	141	118	134	120
• **CASIS commercial[1]**			**3**	**21**	**26**	**19**	**69**
• **NASA commercial[2]**			**2**	**3**	**4**		
Human Resources Total	42	30	29	28	21	29	38
Biology/Biotech	**8**	**14**	**12**	**12**	**22**	**25**	**17**
Education	18	24	22	12	7	5	2
Technology Development	32	25	21	35	15	19	18
Earth and Space Sciences	13	12	8	10	10	14	15
Physical Sciences	**24**	**28**	**31**	**26**	**31**	**25**	**23**
Multipurpose (JSC/MSFC support activities for ISS National Lab	13	12	15	18	12	17	7

[1] www.iss-casis/org/Dashboard.aspx (only **5 had microgravity as the main benefit +investigation with a commercial PI**)

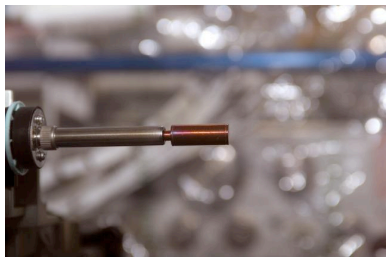
[2] US commercial counted only if microgravity was the main benefit and the investigation had a commercial PI or Co-PI

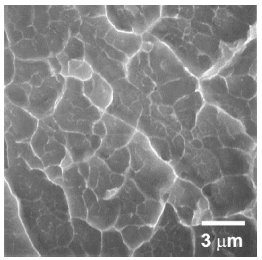
Successes: High TRL Examples

Despite relatively low funding, relatively few investigators, and great difficulties accessing space (compared with laboratory research on Earth), the success rate from microgravity R&D into applications is remarkably significant.

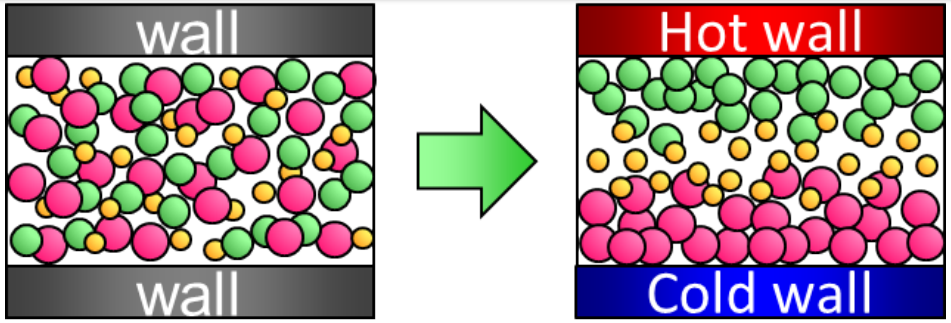


Experiment	Product	μg benefit
Space Beads	Polystyrene spheres 10 microns in diameter-calibration standard SRM 1965 for NBS	Superior product in terms of (1) sphericity (2) narrowness of size distribution (3) rigidity
Bulk Metallic Glasses	Hinges, sliders, frames, display frames, miniature camera case, phone cases, golf clubs, surgical tools, SIM eject tool for iPhone	Helped develop BULK (vs thin) metallic glasses by acquiring understanding in microgravity underlying viscosity of this material.



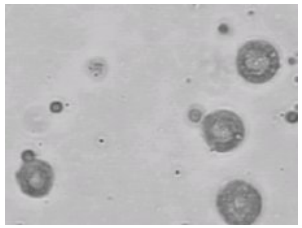
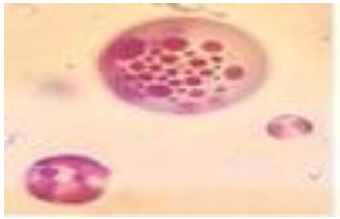
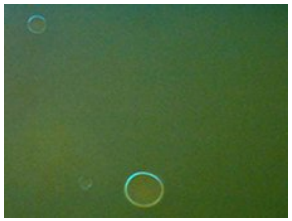
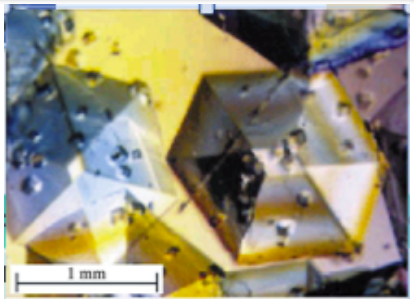


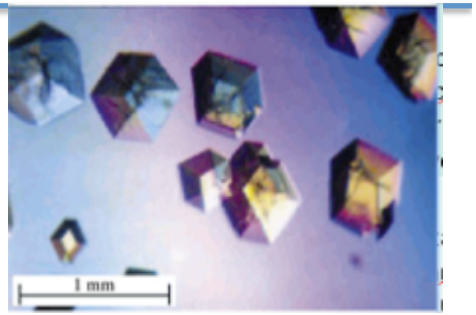
Successes: High TRL Examples



Experiment	Product	μg benefit
Semiconductor crystals	Fabrication of low noise field effect transistors (FET's), analog switch integrated circuits (LCS)	Microgravity-grown crystals have (1) increased single crystal size (2) suppressed impurities and defects (3) higher quality crystals
Thermal Diffusion Coefficients	Database of Soret coefficients for various mixtures	Capturing the diffusive aspect of thermodiffusion (no convection)
Capillary Flow Experiments	Software for modeling of complex interface configurations. New rapid diagnostic for infant HIV for the developing world,	Capturing fluid and bubbles system dynamics as driven by capillary and surface tension forces in microgravity (in the absence of buoyancy driven convection) has resulted in high performance, unique theoretical models.

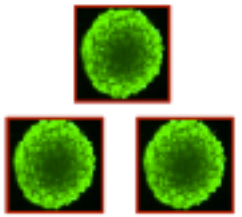
Successes: High TRL Examples

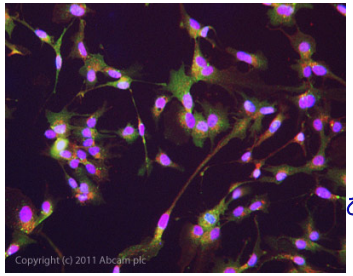





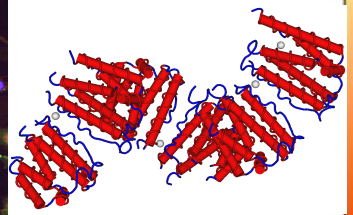


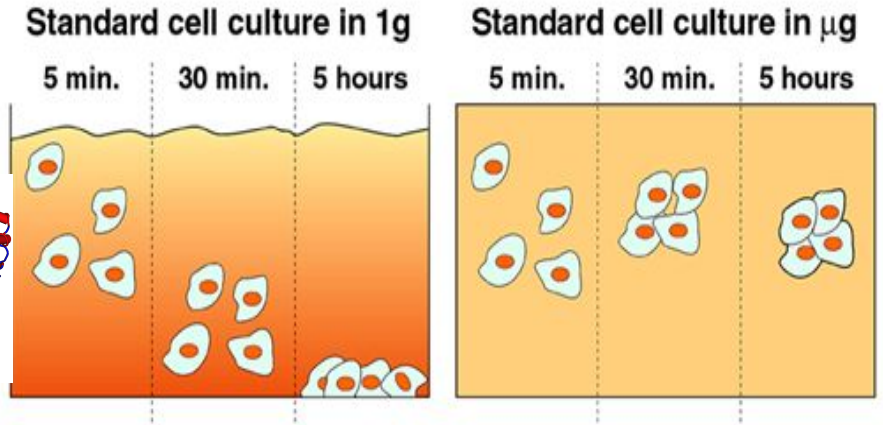
Experiment	Product(s)&Customers	mg benefit
Microencapsulation	Bright Mark line of tissue site marker for accurate tumor diagnostic devices Chemo-FDA approved drugs contained in microcapsules (clinical trials entered in 2012) for local (vs systemic) cancer chemotherapeutic treatment	Pharmaceutical drug and its outer membrane form spontaneously improving ease of drug manufacturing and direct injection into tumoral tissue; controlled layering enables timed delivery of drug.
Insulin crystals	Slow absorption diabetic drug	Well ordered, high resolution crystals of the T3R3 insulin hexamer variant were produced in microgravity resulting in designing a stable form that dissolves at the right rate inside the body[6].

Successes: High TRL Examples









Experiment	Product(s)&Customers	µg benefit
Interferon	FDA approved Peg-Intron™, a pegylated alpha interferon formulation, for the treatment of chronic hepatitis C in January 2001.	STS-Microgravity experiments on alpha interferon, Intron A, for the first time provided Schering Plough Research Institute with large quantities of large, high quality crystals. This was a critical stimulus that enabled the company to demonstrate the crystals' suitability as a long lasting formulation, one of its goals.
3D cell cultures	By 2005-39000 Rotating Wall Vessel/Bioreactor units were used worldwide. Industry standard for 3D tissue cultures (cancer, organ disease, diabetes, aging)	Inspired by characteristics of microgravity, the design minimizes shear and turbulence in the mixing process and produces superior 3-D cell and tissue cultures

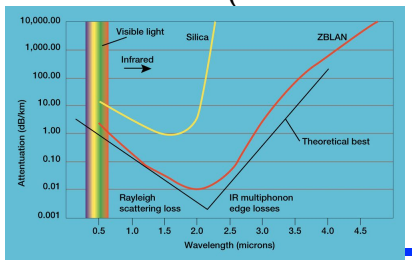
Near Term Potential: Intermediate TRL Examples

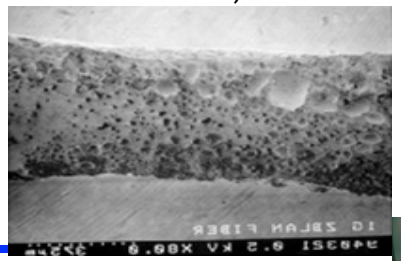
Topic	Company	Potential Application	μg Benefit
ZBLAN optical fibers	Physical Optics Corporation	Mid-IR lasers, Photonics, Thermal imaging, Sensing, Spectroscopy, Biomedical devices, telecom	Fibers made in microgravity would result in very low broadband attenuation (~100x better than currently used Si fibers)
3D tissue and tumor growth	Vivo Biosciences	Growth of patient derived tumor cultures for selection of chemotherapy drugs	Size of tumors grown in microgravity ~10x larger[1] than on ground and of higher tissue fidelity
Zeolite crystals	Catalysts, ion exchangers; absorbents/ separation; hydrogen storage; "green" household products; environment monitoring and control; zeoponic materials; Photocatalysts		Growth of large, uniform, high-quality/ zeotypes ETS titanosilicate crystals; reduced defect concentrations and types; attunement of chemical formulation to control nucleation, growth and chemical control/functionalization
Field-Directed colloidal and nanoparticle self assemblies	Magneto-rheological (MR) dampers for energy absorption (earthquake, automobiles, trucks) Electro-rheological (ER) fluids for haptic controllers and tactile displays in microelectronic devices		Understanding of the mechanisms that govern formation and dissolution of structures for rapid and reversible change of rheological properties. Studies in microgravity offer a unique opportunity to interrogate the structural evolution, pattern formation and aggregation dynamic of dipolar suspensions.

ZBLAN optical fiber –case study

WHY ZBLAN-ZrF4-BaF2-LaF3-AlF3-NaF

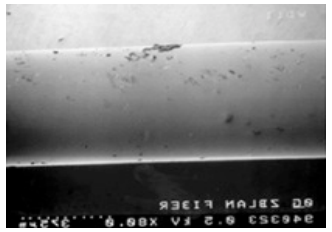
- Most stable fluoride exotic glass and excellent host for doping
- Broad optical transmission window extending from 0.3 microns UV to 7 microns IR
- Theoretical loss for ZBLAN is 0.001dB/km at 2microns (~100x better than Si fibers)

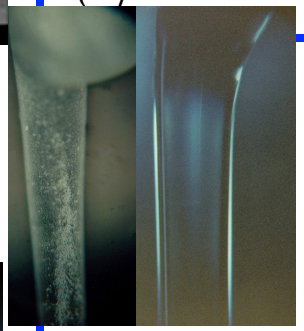




MICROGRAVITY BENEFIT

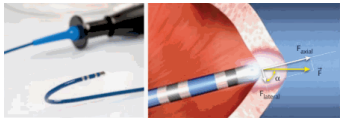
- Microgravity suppresses the effect of nucleation and crystallization –directly underlying attenuation-broadband properties
- No limit to the length that can be produced in space without need to adjust payload size
- 1lb of preform would produce 8 km ZBLAN fiber
- Nominal selling price range on Earth: $175k/km to $1,000k/km ~ROI: 90-300x (w/o amortization costs)



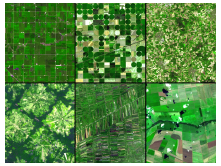


APPLICATIONS

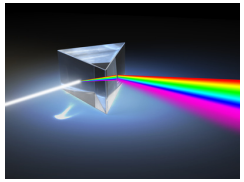
Image fiber bundle



Medical applications

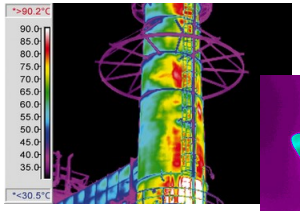


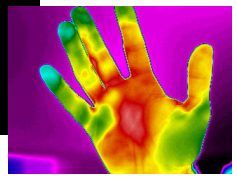
Remote sensing



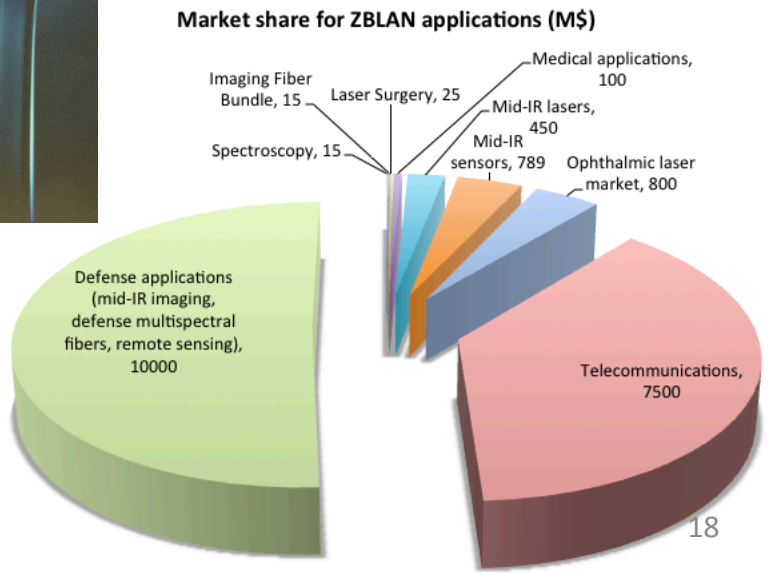
Laser spectroscopy

Mid-IR lasers





Thermal imaging



3D Tissue Cultures – Case Study

- Vivo Biosciences Inc. (VBI) is an award winning company with a customer base that includes major pharmaceutical companies.
- VBI's technology is used to grow tissues and tumors for cancer research and selection of chemotherapeutic agents.
- To develop better life-saving therapeutic options, VBI needs 3-D tissues and tumors that are both bigger than what they can achieve on Earth. Gravity is the limiting constraint.
- Space grown 3-D tissues have exhibited some superior properties to terrestrial tissues.

VBI does not know whether growing tumors in space will improve their products performance, but they have reached the limit of what they can do on Earth and gravity is the problem.

If successful, the results would be important to many research areas, including selecting the right chemotherapy options for patients.

This is potentially life-saving research that could offer significant near-term benefits to the public.

Next Generation Technologies: Low TRL Examples

Topic	Potential Application	Hypothesized *μg* benefit
Hollow ball bearings	Load-bearing machines with moving parts, tribology (earthquake protection, computer hard drives, electronic devices)	High sphericity, narrow size distribution, hollow monolithic spheres; multiple layered hollow ball bearings of different materials
DNA 3D self assemblies	DNA nanotechnology, DNA based computing,	Improvement in diffraction quality of DNA self-assembly crystals to characterize inter-molecular contacts.
Nanoclays	Polymer nanocomposites, flammability inhibitors, rheological modifiers, gas absorbents, liquid crystal displays, drug delivery carriers	More uniform clay-polymer mixtures generated in the microgravity environment with reduced mixing time.
Light sensitive membrane proteins	Study of neural systems and diseases (Parkinson, Huntington, etc)	Crystallization of membrane proteins with high resolution and clarity for engineering better ground counterparts. Current crystals on ground do not diffract
Ultra thin coatings	Biocompatible coatings for implanted batteries, devices; Photovoltaic coatings; Manufacture of semiconductor components; Magnetic information storage systems; Photoresist microelectronics	In a gravitational field the gravitational force acts parallel to the flow thereby creating shear stresses in the film and introducing 3D instabilities (Waves, ribs, streaks) that interfere with the manufactured device performance. In microgravity the surface tension forces and viscous forces in the meniscus region would lead to smooth, uniform and highly accurate thin films.

TOPICS

New materials

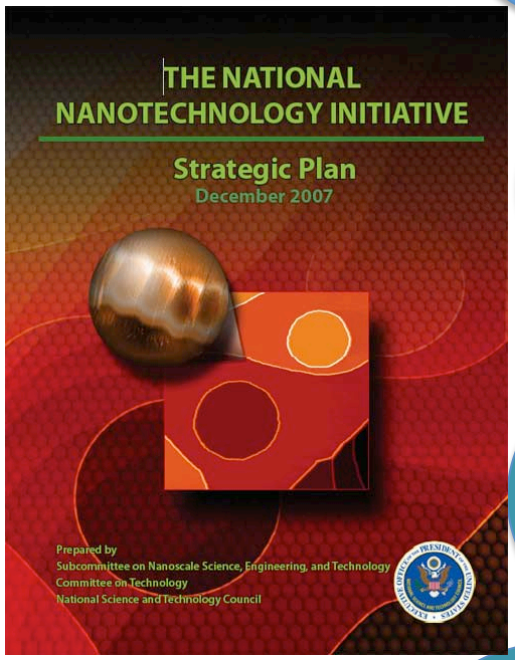
Microstructure formation

Particle self-assemblies

Polymers, ceramics

Protein crystals

In the current landscape of national needs



Metal alloys, semiconductor

MICROGRAVITY and NANOTECHNOLOGY

cover the same topics and have comparable potential for breakthrough for multiple applications

Communications
Fiber optics

Micro fluidics
Oil extraction

Cancer research
New organs

Catalysis
Automotive

Energy collection and conversion

Micro- and nano-electronics
Nanotechnology

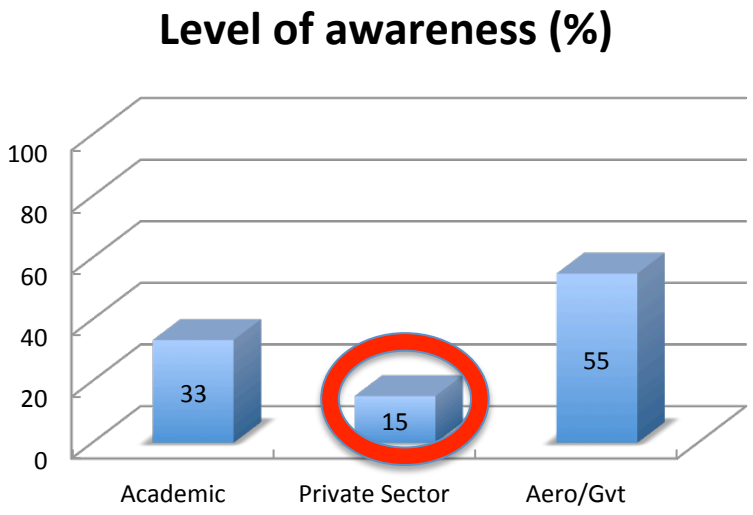
APPLICATIONS

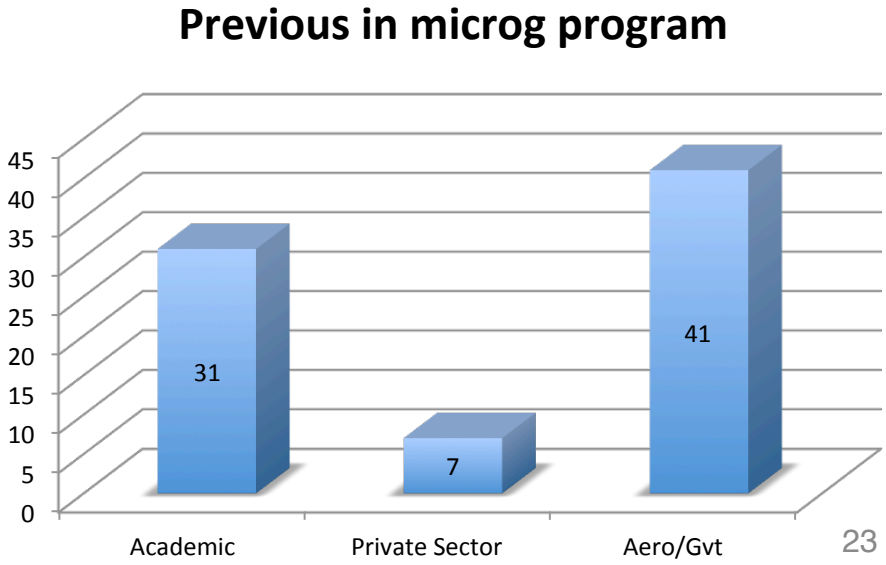
Awareness, accessibility and interest

The unawareness is large.
The interest is considerable.
Better structured information is desired

The unawareness is large

- Most high-tech academics and industry practitioners are not aware of the value of microgravity to their work or that the ISS is accessible to them.
  - Of the 111 academics contacted, only 33% were aware of microgravity potential (31% of the 111 were former microgravity PIs)
  - Of the 132 private sector practitioners contacted in a wide variety of technical fields, only 15% were aware of microgravity potential (7% of the 132 were former microgravity PIs)
  - Even of the aerospace/government communities surveyed, only 55% of the 51 individuals contacted were aware of the value of microgravity, and of those 41% were prior microgravity PIs.





Dialogue with Industry and Academia

- What are your current R&D interests?
- What are your current technical challenges?
- What are your short and long term business goals?
- What could be the best value that microgravity could provide you?

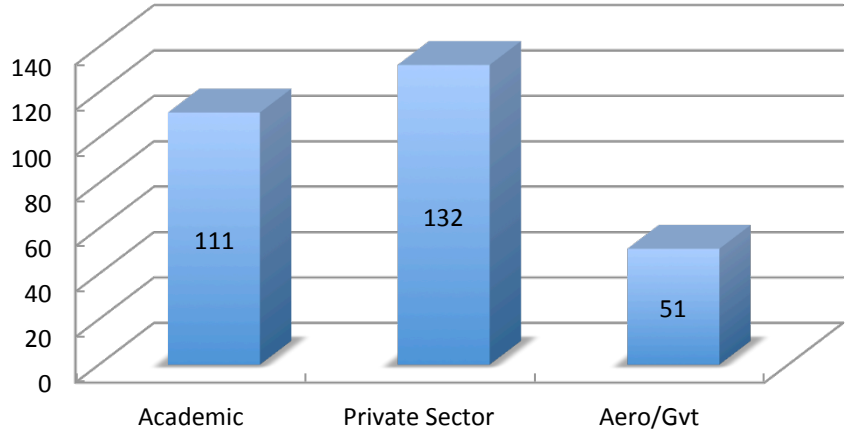
- Engage in an open, honest dialog
- Face to face is better than telecon
- Folllow-up with the promised material
- Ask the other party to provide feedback
- Be prepared with compelling examples if they exist or make correlations to other investigations where findings could be translated
- Admit we don't know everything
- Admit what we don't have in terms of capabilities
- Apologize for past inefficiencies, bureaucracies
- Restate that we do want to provide better services and be responsive

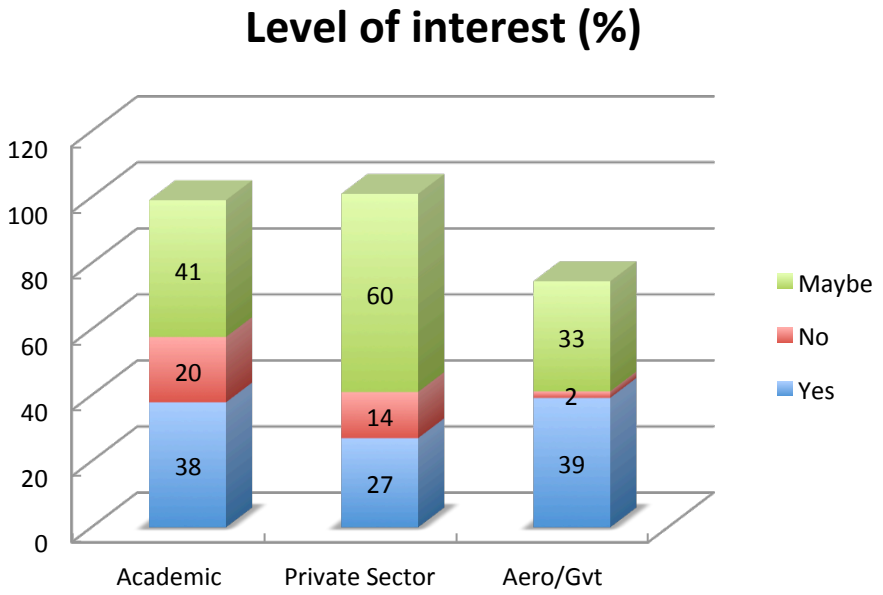
Universities: Caltech, Stanford, Texas A&M, Austin, UCLA, UIUC, Purdue

Companies: IBM, Intel, SGI, DuPont, Novartis, AMat, Brocade, Merk, City of Hope, Nestle, Genentech

The interest is considerable…

- Of 111 academics: 38% expressed clear interest and 41% potential interest in microgravity research
- Of 132 professionals in the private sector: 27% expressed clear interest and 60% potential interest in microgravity research
- Of 51 aerospace professionals: 39% expressed clear interest and 33% potential interest in microgravity research





What is the role of Silicon Valley in the next 10 years of International Space Station operation?

FEEDBACK FROM SILICON VALLEY

- Microgravity is increasingly intriguing.
- Maintaining an open, collaborative dialogue is critical.
- A one-stop access point for microgravity related R&D and commercialization is needed.
- Provide traceability between microgravity driven discoveries and revenue generating companies/spinoffs.
- Public expectations for microgravity-based discoveries are disproportionate to current investments and difficulty.
- Still too high risk for private investors, government will need to prime the pump.
- Apply the culture of Silicon Valley (stimulate startups that use microgravity for new product innovation; microgravity accelerator program, etc.) to stimulate commercialization of microgravity
- Need for an educational program across disciplines dedicated to prepare the next generation of academic and commercial microgravity R&D users